REPORT UAG-7

WORLD DATA CENTER A

Upper Atmosphere Geophysics

OBSERVATIONS OF THE SOLAR CORONA: FEBRUARY 1964 - JANUARY 1968

October 1969

WORLD DATA CENTER A

National Academy of Sciences

2101 Constitution Avenue, N. W. Washington, D. C. U.S.A., 20418

World Data Center A consists of the Coordination Office

and eight subcenters:

World Data Center A
Coordination Office
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D. C., U.S.A. 20418
Telephone (202) 961-1404

Airglow, Aurora (Instrumental and Visual):
Cosmic Rays, Ionosphere and Solar Activity:
World Data Center A:
Upper Atmosphere Geophysics
Environmental Science Services Administration
Boulder, Colorado, U.S.A. 80302
Telephone (303) 447-1000 Ext. 3654

Geomagnetism, Seismology, Gravity and Tsunami:
World Data Center A:
Geomagnetism, Seismology, Gravity & Tsunami
Environmental Data Service, ESSA
Rockville, Maryland, U.S.A. 20852
Telephone (301) 496-8160

Glaciology:
World Data Center A:
Glaciology
American Geographical Society
Broadway at 156th Street
New York, New York, U.S.A. 10032
Telephone (212) 234-8100

Longitude and Latitude:
World Data Center A:
Longitude & Latitude
U.S. Naval Observatory
Washington, D.C., U.S.A. 20390
Telephone (202) 698-8422

Meteorology (and Nuclear Radiation):
World Data Center A:
Meteorology
National Weather Records Center
Asheville, North Carolina, U.S.A. 28801
Telephone (704) 253-0481

Oceanography:
World Data Center A:
Oceanography
Building 160
Second and N Streets, S.E.
Washington, D. C., U.S.A. 20390
Telephone (202) 698-3753

Rockets and Satellites:
World Data Center A:
Rockets and Satellites
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D. C., U.S.A. 20418
Telephone (202) 961-1404

Upper Mantle Project:
World Data Center A:
Upper Mantle Project
Lamont Geological Observatory
Palisades, New York, U.S.A. 10964
Telephone (914) 359-2900 Ext. 209

Notes:

(1) World Data Centers conduct international exchange of geophysical observations in accordance with the principles set forth by the International Council of Scientific Unions. WDC-A is established in the United States under the auspices of the National Academy of Sciences.

(2) Communications regarding data interchange matters in general and World Data Center A as a whole should be addressed to: World Data Center A, Coordination Office (see address above).

(3) Inquiries and communications concerning data in specific disciplines should be addressed to the appropriate subcenter listed above.

WORLD DATA CENTER A

Upper Atmosphere Geophysics

REPORT UAG-7

OBSERVATIONS OF THE SOLAR CORONA: FEBRUARY 1964-JANUARY 1968

by

Richard T. Hansen

High Altitude Observatory

Boulder, Colorado and Kamuela, Hawaii

Prepared by Research Laboratories, ESSA, Boulder, Colorado
and published by

U.S. DEPARTMENT OF COMMERCE

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

ENVIRONMENTAL DATA SERVICE

ASHEVILLE, NORTH CAROLINA, USA 28801

October 1969

SUBSCRIPTION PRICE: $9.00 a year; $2.50 additional for foreign mailing; single copy price varies.* Checks and money orders should be made payable to the Superintendent of Documents. Remittance and correspondence regarding subscriptions should be sent to the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

*Price of this issue 15 cents

OBSERVATIONS OF THE SOLAR ELECTRON CORONA: FEBRUARY 1964 - JANUARY 1968

by

Richard T. Hansen
High Altitude Observatory
Boulder, Colorado and Kamuela, Hawaii

1. OBSERVATIONS

The purpose of this report is to summarize briefly the work with the High Altitude Observatory's K-coronameter during the period July 1963 to January 1968. Earlier observations with the same instrument, then operated at Climax, Colorado, are reproduced in the following publications of the IGY Solar Activity Data Center:

> Report No. 4 by G. Newkirk, Jr., G. W. Curtis and K. Watson for the period September 1956 - January 1958 (38 days data);
>
> Report No. 16 by Chr. E. Heynekamp for the period January 1958 - November 1960 (132 days data).

During the summer of 1963 the observing program with the instrument at Climax was discontinued and in September of that year the K-coronameter was installed in the Mees Solar Laboratory of the Hawaii Institute of Geophysics's Haleakala Observatory as a collaborative program between the University of Hawaii and the High Altitude Observatory with special support from the National Science Foundation as part of the United States effort for the International Years of the Quiet Sun. Photometrically useful measurements of the white light corona began in February 1964 and continued at Haleakala until November 1965 when the instrument was relocated to its present site at the Environmental Science Services Administration's Mauna Loa Observatory (11,150) feet elevation). The physical setting of this mountain laboratory and the meteorological factors which established its suitability for coronagraphic observations are described by Price and Pales (1963) and Hansen, Hansen and Price (1966).

The K-coronameter is a Photoelectric Polarimeter incorporated into a Lyot coronagraph for the study of the sun's electron corona outside of natural eclipse (Wlérick and Axtell 1957; Axtell 1958; Lee and Fullerton 1961). The data reduction and calibration techniques have been described earlier (Newkirk, Curtis and Watson 1958; Heynekamp 1962) and were continued without change during the more recent period. Two details are worthy of note: All of the observations in Hawaii were made with the same scanning aperture of diameter 0.0292" so that the effective spatial resolution was consistently 1.3 minutes of arc; and second, all observations were calibrated with Newkirk's filter Number 4 of nominal transmission 1.8×10^{-4} so any error in the original calibration or progressive deterioration of the filter would be directly reflected in the newer data.

The specific dates having K-coronameter observations during the period February 1964 to January 1968 are enumerated in Appendix. The amount of data is too great for inclusion in this volume and is furthermore probably too specialized to warrant the expense of complete publication. Persons with specific interest in this material may contact the author.

A typical example of a daily coronal survey is shown in Figure 1 in the form of a polar plot of the brightness as a function of position angle at successively greater distance from the solar limb. The outermost trace represents the brightness distribution of the innermost corona because the corona has a steep gradient. (The representation should not be confused with the frequently-presented isophote form.) For many days it was possible to observe only the inner regions of the K-corona (at a distance of 1.125 R_o) due to any of several unfavorable conditions such as the early formation of clouds above the observatory or the presence of excessive amounts of smoke, dust, or insects in the air path between the telescope and the sun. But on many other days, particularly during the years 1966-1967, it was possible to extend measurements to 2.0 R_o, a radius above the solar limb.

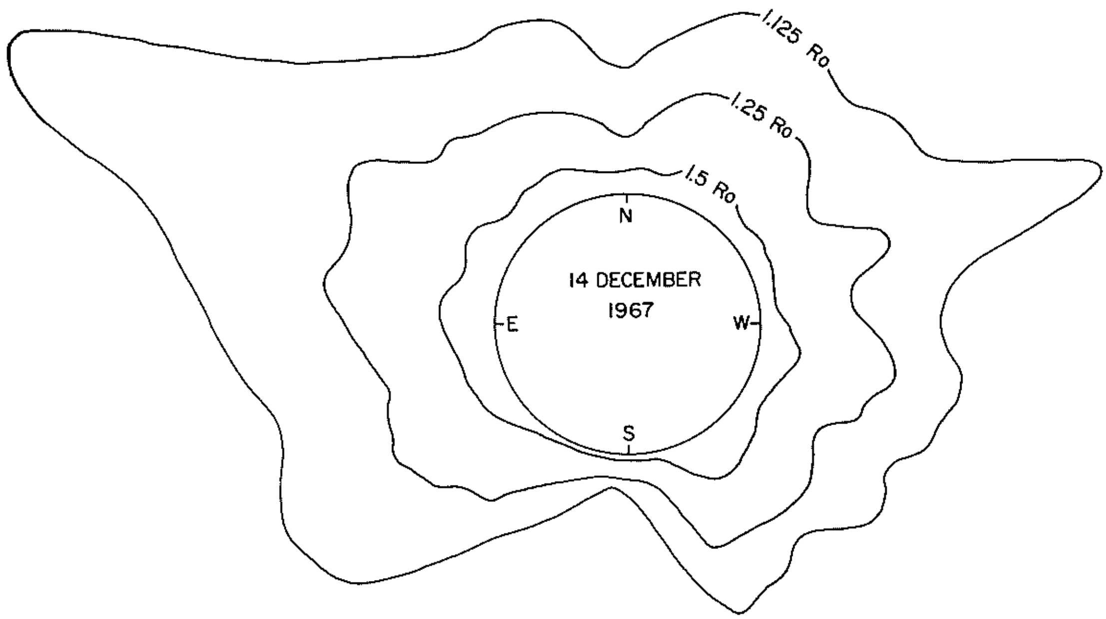

Figure 1. Typical daily coronal survey.

2. ANALYSIS

A detailed description of the evolution of the brightness distribution from the minimum year 1964 through the ascending phase of cycle 20 is given by Hansen, Garcia, Hansen and Loomis (1969). Their abstract follows:

> Observations of the white light corona were made on over 900 days during the years 1964-1967 at heights between 1.125 and 2.0 R_o with the K-coronameter at Mount Haleakala and Mauna Loa, Hawaii. The brightness distribution of the minimum corona was elliptical with average equatorial intensities three times the polar. Coronal features of the new cycle at 1.125 R_o occurred predominantly in the sunspot zones at 25-30° latitude and in a high latitude zone which migrated toward the North pole before solar maximum. The brightness of the inner corona doubled over this period and a close association is found between the average corona and 10.7-cm solar radio flux. Electron densities in the equatorial regions were nearly twice those of Van de Hulst's model corona, in agreement with the results of recent eclipse observations.

In Figure 2, representative daily measurements at 1.125 R_o are superposed for each of the four years. They show the relative constancy of the corona during 1964 and then the gradual development of discrete features, two to three times brighter than the minimum corona, at preferred latitudes. The Northern hemisphere was distinctly more active than the Southern in 1966.

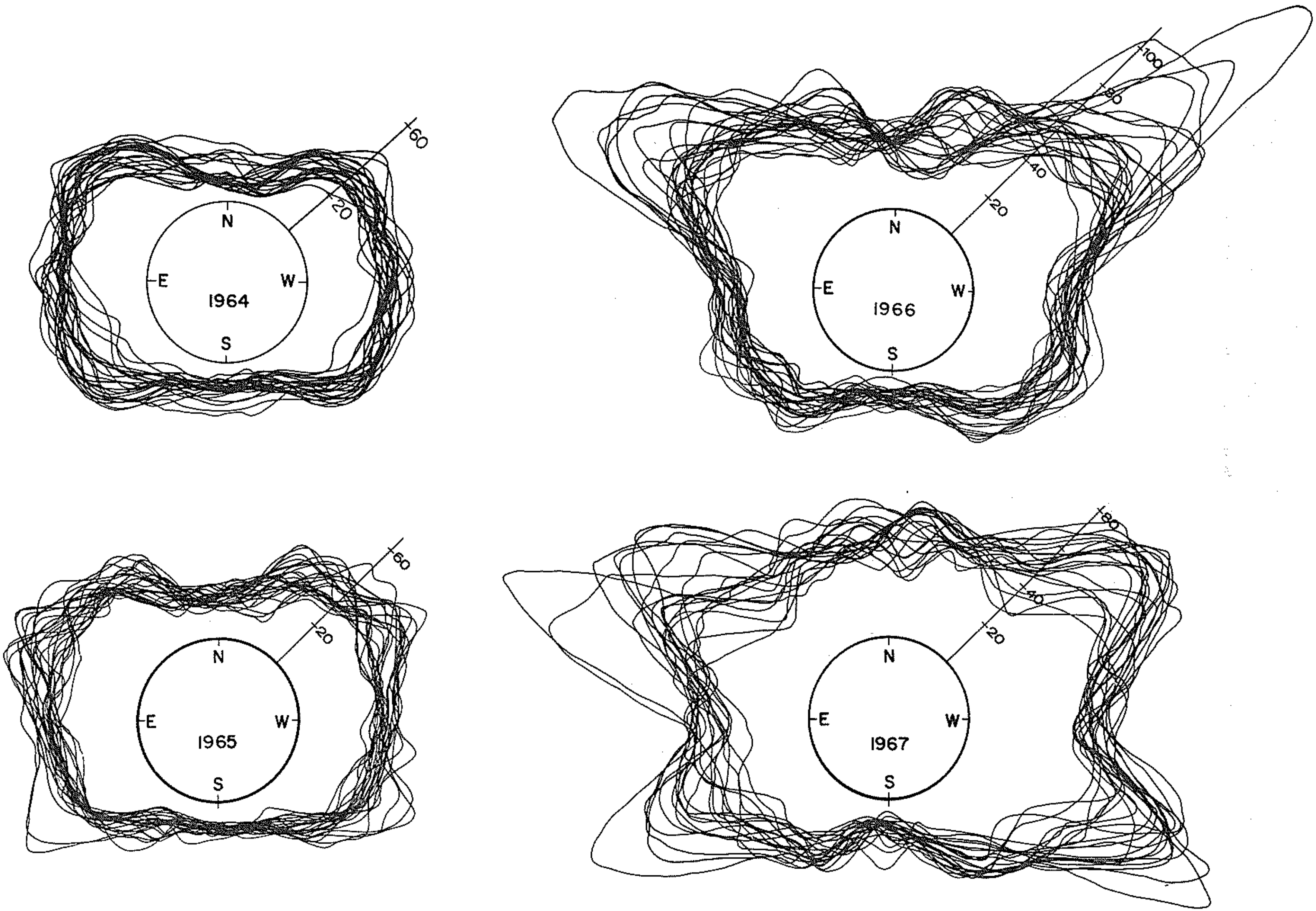

Figure 2. The variation in brightness distribution of the inner K-corona between the years 1964-1967. The quantity "pB" is plotted radially as a function of position angle for daily observations at 1.125 R_o for each month of July.

The differential rotation of the sun's corona was also studied for the same time period (Hansen, Hansen and Loomis 1969). A principal result is shown in Figure 3 where the average rotation rate of K-coronal features as a function of latitude is compared with that found from other solar phenomena. The agreement is generally quite close at low latitudes, but in the range 55-65° the corona seems to rotate nearly 2°/day faster than the photosphere, as indicated by studies of the day-to-day displacement of polar faculae.

> Abstract: Autocorrelation analyses of K-coronameter observations made at Haleakala and Mauna Loa, Hawaii during 1964-1967 have established average yearly rotation rates of coronal features as a function of latitude and height above the limb. At low latitudes the corona was found to rotate at the same rate as sunspots but at higher latitudes was consistently faster than the underlying photosphere. There were differences as large as 3-4% in the rate at specific latitudes from year to year and between the two hemispheres. In 1967 a nearly constant rotation was found for heights ranging from 1.125 to 2.0 R_{O}. For 1966 there was a more complicated pattern of height dependence, with the rate generally decreasing with height at low latitudes and increasing at high latitudes.

As part of the "Cooperative Study of Solar Active Regions" (CSSAR) project of the International Years of the Quiet Sun (IQSY), the Haleakala K-coronameter records for 10 March-30 October 1965 were made available for a study of the relationship between coronal emission and plage regions. The analysis was reported by Leroy, Rösch and Trellis (1968) at the International Astronomical Union (IAU) Symposium in Budapest, and their abstract states:

> A study of the development in the solar corona of active centers born during the CSSAR period leads to the following remarks: the "enhancement" of coronal emissions seems to take place first within a localized "core" close to the plage, then to extend to a much larger "halo"; the core from which all the radiations under study originate does not last much more than the spots, whereas the "halo" is characterized by the major importance of the emission at 5303 A, and lasts as long as the K3 plages. These features can be explained by the assumption that the enhancement is inhomogeneous during the first part of its life, then becomes homogeneous after the core has disappeared.

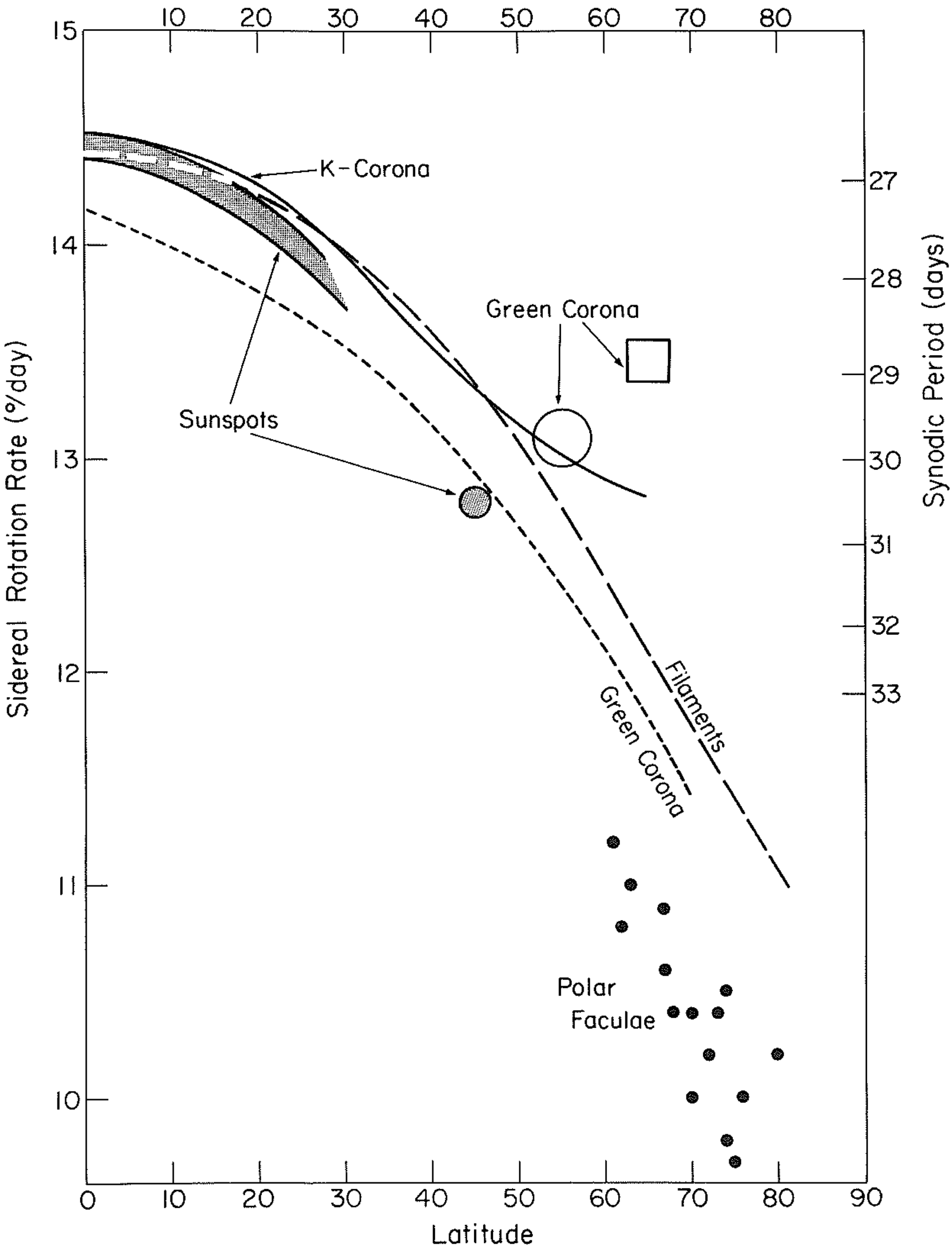

Figure 3. The average rotation rate of K-coronal features during the years 1964 - 1967 compared with rates for other solar phenomena, taken from Hansen, Hansen and Loomis (1969).

Also under IAU and IQSY sponsorship was the Proton Flare Project (PFP) of 1966. Newkirk, Hansen and Hansen (1968) reported on the analysis of the Mauna Loa data as follows:

> K-coronameter observations during the interval June-September 1966 are used to construct five electron density models of the corona above the proton flare region. These models are compared with others for the corona above active regions. The observations following the proton flares of 10 July and 5 September show the presence of a unique low elevation condensation in the corona. The possibility that this condensation is the direct contribution of material expelled by the flares is examined.

The K-coronal measurements were also combined with data obtained from three stratospheric balloon flights of Coronascope II (5 March 1964, 30 June and 1 July 1965) plus photographs of the corona at the eclipse of 30 May 1965 in an extensive study of the structure, dynamics and evolution of solar coronal streamers (Bohlin, 1968). The results were reported to a meeting of the National Academy of Sciences (Bohlin, Newkirk and Hansen 1968) as follows:

> Although total solar eclipses have been scientifically observed for decades, their infrequency and short duration precluded investigation of the streamers into which the white-light corona is structured. Even the most rudimentary characteristics of streamers, such as spatial location, evolutionary patterns, and associated phenomena, remained largely speculative, or at best, ambiguous. Unprecedented time resolution (extending over 32 days) of these streamers was obtained in 1965 using an externally-occulted coronagraph (the Coronascope II project) operating in the stratosphere, coupled with the May 1965 total solar eclipse. These photographic data (out to 6 solar radii from the sun) were cross-identified with nearly daily observations of the innermost corona from a land-based, photoelectric scanning coronagraph to yield solar disk location of 12 coronal streamers. These streamers were traced in the K-coronameter data to show that streamers clearly partake in the general solar rotation and can have lifetimes as long as 4 or 5 solar rotations (110 to 140 days). Streamers evolve slowly, appearing almost quasi-stationary over periods of several months. However, occasionally rapid changes in just 14 days were found. Their density structure

could be described by a radially-dependent core density which decreased as a gaussian in directions perpendicular from the core line. Typical 1/e-contour dimensions were 30° extent in latitude by 40° in longitude, measured heliocentric. Streamers were always found in near association with complexes of solar activity as manifested by sunspots and plages.

Other studies resulting from the K-coronameter work include: Calculations of the variation in the appearance of an idealized solar streamer as it rotates around the limb of the sun (Perry 1967); the association between K-coronal features and other solar phenomena (in preparation); a description of the evolution of the coronal features seen at the 12 November 1966 eclipse (Hansen, Hansen and Garcia 1967); corroboration of Surveyor I observations of the corona (Norton, Gunn, Livingston, Newkirk and Zirin 1967); and comparison between solar wind and coronal intensities (in preparation).

3. ACKNOWLEDGEMENTS

The work reported here is the result of specific contributions by many individuals. Charles Garcia shared with the author responsibility for daily operation and maintenance of the K-coronameter. Robert Lee frequently assisted in difficult electronic problems.

Mrs. Shirley Hansen carried out the data reduction with the help of a number of part-time assistants including Jon Okada, Mike Perry, Ronald Kwon, Mrs. Joyce Foster, Mrs. Nancy Edwards, Miss Lois Kawabata and Miss Nadine Kurokawa. The statistical studies were done by Dr. Harold Loomis with the University of Hawaii's computing facilities.

Installation of the K-coronameter at Haleakala in 1963 was supported by a grant from the National Science Foundation for purchase of a Boller and Chivens Equatorial Spar and Photoelectric Guiding system, duplicating the Sacramento Peak designs of Dr. Richard Dunn and Dr. Edwin Dennison. Operation of the instrument at Haleakala was made possible by the cooperation of Dr. Walter Steiger and Dr. John Jefferies of the University of Hawaii and, at Mauna Loa, by Howard Ellis and Lothar Ruhnke of the Environmental Science Services Administration.

Dr. John Firor and Dr. Gordon Newkirk gave us their continued enthusiasm and support.

REFERENCES

AXTELL, J.	1958	A Study of the Polarized Component of the Solar Electron Corona (Thesis, University of Colorado, Boulder, Colorado).
BOHLIN, J. D.	1968	Structure, Dynamics and Evolution of Solar Coronal Streamers (Thesis, University of Colorado, Boulder, Colorado).
BOHLIN, J. D., G. NEWKIRK and R. T. HANSEN	1968	The Structure, Evolution and Associated Phenomena of Solar Coronal Streamers. Paper presented at the autumn meeting of the National Academy of Sciences, Pasadena, California.
HANSEN, R. T., S. F. HANSEN and SAUL PRICE	1966	An Example of Meteorological Considerations in Selecting an Observatory Site in Hawaii, P.A.S.P., 78, 14.
HANSEN, R. T., S. F. HANSEN and C. J. GARCIA	1967	The Solar Electron Corona of 12 November 1966, A. G. Memo No. 174, High Altitude Observatory, Boulder, Colorado.
HANSEN, R. T., C. J. GARCIA S. F. HANSEN and H. LOOMIS	1969	Brightness Variations of the White Light Corona during the Years 1964-1967, Solar Physics (in press).
HANSEN, R. T., S. F. HANSEN and H. LOOMIS	1969	Differential Rotation of the Solar Electron Corona, submitted to Solar Physics.
HEYNEKAMP, C. E.	1962	Observations of the Solar Electron Corona: January 1958-November 1960, IGY Solar Activity Report Series No. 16, 4 July 1962, High Altitude Observatory, Boulder, Colorado.
LEE, R. H. and J. G. FULLERTON	1961	K-Coronameter Observes the Sun's Electron Corona, Electronics, 34, 58.
LEROY, J. L., J. RÖSCH and M. TRELLIS	1968	Evolution des Emissions Coronales au Cour de la Vie d'un Centre Actif. Structure and Development of Solar Active Regions, Ed. K. O. Kiepenheuer (Reidel Publ. Co., Dordrecht, Holland).
NEWKIRK, G., G. W. CURTIS and D. K. WATSON	1958	Observations of the Solar Electron Corona: September 1956-January 1958. IGY Solar Activity Report Series No. 4, 15 August 1958, High Altitude Observatory, Boulder, Colorado.

NEWKIRK, G., R. T. HANSEN and S. HANSEN	1968	Coronal Electron Densities during the Period of the July 1966 Proton Flare, Annals of the IQSY, 3, 49-62.
NORTON, R. H., J. E. GUNN, W. C. LIVINGSTON, G. A. NEWKIRK and H. ZIRIN	1967	Surveyor I Observations of the Solar Corona, J.G.R., 72, 815.
PERRY, R. M.	1967	Variation in the Appearance of a Coronal Streamer with Solar Rotation, A. G. Memo No. 175, High Altitude Observatory, Boulder, Colorado.
PRICE, S., and J. C. PALES	1963	Mauna Loa Observatory: The First Five Years, Monthly Weather Review, 91, 665.
WLÉRICK, G., and J. AXTELL	1957	A New Instrument for Observing the Electron Corona, Astrophys. J., 126, 253.

APPENDIX

DAYS OF CORONAL OBSERVATIONS

Year 1964

Days	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1			X	X	X		X	X	X			
2				X	X		X		X	X	X	
3			X	X	X	X	X	X	X	X		
4			X	X	X	X	X	X		X		
5			X		X	X	X			X		
6			X	X	X	X		X	X			
7			X	X	X	X	X	X	X			
8				X	X	X	X	X		X		
9			X	X	X	X	X	X	X	X		
10			X	X	X	X	X		X	X		
11				X	X	X		X	X	X		
12			X	X	X	X		X	X	X	X	
13			X			X	X	X	X	X	X	
14		X	X	X	X	X		X	X	X		
15			X		X		X		X	X		
16		X	X		X			X				
17			X			X	X	X	X	X	X	
18		X				X	X	X	X	X	X	
19		X				X		X	X	X		
20		X				X	X	X	X			
21		X					X	X	X			
22							X	X	X	X		
23							X	X		X		
24						X		X		X		
25		X					X	X	X			
26		X					X	X				
27		X					X		X			
28		X			X		X	X	X			
29		X			X	X		X	X			
30						X	X	X	X			
31					X		X	X				

Year 1965

Days	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	X		X				X		X			
2	X	X	X		X		X	X	X	X	X	
3			X			X	X	X	X	X	X	
4	X		X	X		X	X	X	X		X	
5	X		X			X	X	X	X	X		
6		X	X			X	X	X	X	X		
7		X	X			X			X	X		
8			X	X	X	X		X	X			
9		X	X	X	X				X			
10		X	X	X		X	X	X	X	X		
11	X	X	X	X		X	X	X				
12	X	X	X				X	X		X		X
13			X			X	X		X			
14			X	X	X	X	X	X	X			
15		X	X	X			X		X	X		X
16	X	X	X	X		X	X	X	X		X	X
17	X	X	X			X	X	X	X	X		
18	X	X	X			X	X	X			X	
19	X	X	X	X		X		X	X	X		
20	X	X	X			X	X	X	X			
21	X	X			X	X	X	X	X	X	X	
22	X	X	X	X	X	X	X	X		X	X	
23		X	X	X	X	X	X	X		X	X	
24		X	X	X	X	X	X	X		X	X	X
25		X	X	X	X	X		X		X	X	X
26		X	X	X	X	X	X	X	X	X		
27		X		X	X	X	X	X	X	X		X
28		X			X	X	X	X	X	X	X	X
29				X		X	X	X	X	X	X	X
30					X	X	X	X		X		X
31							X	X		X		X

APPENDIX CONTINUED

Days of Coronal Observations

Year 1966

Days	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1				X	X	X	X		X	X	X	X
2		X		X	X	X	X	X	X	X	X	
3	X	X			X	X	X		X	X		X
4	X	X		X	X	X	X	X	X	X		X
5				X		X	X	X	X	X		X
6	X		X			X	X	X	X			X
7	X		X	X	X		X	X	X	X	X	
8				X		X	X	X	X	X	X	X
9		X		X	X	X	X	X	X		X	X
10	X	X					X	X			X	X
11	X	X				X	X	X	X		X	X
12	X		X		X	X	X	X	X		X	X
13				X	X	X	X	X	X			X
14	X		X	X		X		X	X		X	X
15	X		X	X		X	X	X	X		X	
16	X		X	X		X	X	X	X		X	X
17				X	X	X	X		X		X	X
18	X			X	X		X	X	X			X
19	X			X	X	X	X	X	X			X
20				X		X	X	X	X	X	X	X
21		X		X		X	X	X	X	X		X
22	X	X	X	X		X	X	X		X		X
23	X		X	X	X	X	X	X		X		X
24	X		X	X	X	X	X	X		X		X
25	X		X	X		X	X	X		X		X
26	X		X	X	X	X	X			X		X
27	X	X	X	X	X	X	X		X	X	X	X
28	X	X	X	X	X	X		X			X	X
29	X		X	X							X	
30	X		X		X			X	X		X	
31	X		X		X		X	X		X		

Year 1967

Days	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	X					X		X	X	X	X	X
2	X	X				X	X	X	X	X		
3	X	X	X				X		X	X	X	
4		X	X	X		X	X		X	X	X	
5	X	X	X				X	X	X	X		
6	X		X		X	X	X	X	X	X		
7	X	X	X	X		X		X	X	X		
8	X	X		X		X			X	X		X
9	X			X	X	X	X			X		
10	X	X		X		X	X	X	X	X	X	
11		X	X	X			X	X	X	X	X	X
12		X	X	X			X			X	X	X
13	X		X	X			X	X	X		X	X
14			X	X	X	X	X	X	X		X	X
15			X	X	X	X	X	X		X	X	X
16			X	X	X	X		X	X	X	X	X
17		X	X	X		X	X	X	X			X
18	X	X	X	X	X	X	X	X	X			X
19	X		X	X	X	X	X	X	X		X	X
20	X	X		X	X	X	X	X	X		X	X
21	X	X		X	X	X		X	X	X	X	X
22	X	X			X	X	X	X	X	X	X	X
23	X	X			X	X			X	X	X	X
24	X	X			X	X	X		X	X		X
25	X	X				X			X	X		X
26	X	X		X		X	X		X	X		X
27	X	X			X	X	X		X			X
28	X						X	X	X			X
29	X			X			X	X		X		
30	X		X		X	X	X		X	X	X	
31					X		X	X		X		X

USCOMM-ESSA-ASHEVILLE-10-31-69-1000